AMERICAN *ASTRONAUTICAL* SOCIETY

THE AMERICAN INSTITUTE OF AERONAUTICS ANI) ASTRONAUTICS SPACECRAFT GUIDANCE, NAVIGATION AND CONTROL INTERFACE STANDARDS INITIATIVE: OVERVIEW

G.F. Sevaston[1] with F. Agardy[2], J. Allen[3], F. Bauer[4], T. Bauer[5], J. Bone[6], D. Caldwell[7], J. Caggerino[8], D. Challoner[9], J. Clingan[10], R. Crum[1], T. Darone[12], L. Dorsky[13], R. Dynes[14], R. Flanagan[15], P. Graves[16], J. Gambino[17], D. Krueger[18], R. Meya[19], D. Pruett[20], W. Radford[21], O. Rodriguez-Alvarez[22] and D. Ward[23]

[1,7,13]Jet Propulsion Lab., [2]Aerospace Corp., [3]Daedalian Systems Corp., [4,17,18,22,23]Goddard Space Flight Center, [5]Microcosm, [6]Lockheed Missiles and Space Co., [8]Air Force Phillips Lab. [9]Hughes Aircraft Co. [10,15]Boeing, [11,19]Honeywell Satellite Systems, [12]Space Applications Corp., [14]Aero Astro, [16]Martin Marietta Astro Space

18th ANNUAL AAS GUIDANCE AND CONTROL CONFERENCE

February 1-5, 1995
Keystone, Colorado

Sponsored by
ROCKY MOUNTAIN SECTION
AMERICAN ASTRONAUTICAL SOCIETY

THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS SPACECRAFT GUIDANCE, NAVIGATION AND CONTROL INTERFACE STANDARDS INITIATIVE: OVERVIEW

George 1. Sevaston[1],
with Frederic Agardy[2], John Allen[3], Frank Bauer[4], Tom Bauer[5], Jeff Bone[6], Doug Caldwell[7], John Casserino[8], Dorian Challoner[9], Jerry Clingan[10], Ray Crum[11], Tom Darone[12], Len Dorsky[13], Richard Dynes[14], Richard Flanagan[15], Paul Graves[16], Joel Gambino[17], Donald Krueger[18], Robert Meya[19], David Pruett[20], Wade Radford[21], Otilia Rodriguez-Alvarez[22] and David Ward[23]

The American Institute of Aeronautics and Astronautics (AI AA) has undertaken an important new standards initiative in the area of spacecraft Guidance, Navigation and Control (GN&C) subsystem interfaces. The central objective of this effort is to establish standards that will promote plug and play compatibility of major GN&C components, thus enabling substantially lower spacecraft development costs. The standardization targets are specifically limited to interfaces only, including information (i. e., data and signal), power, mechanical, thermal and environmental interfaces between various GN&C components and between GN&C subsystems and other subsystems. The current emphasis is on information interfaces between various hardware elements (e. g., between star trackers and flight computers). The paper will describe the program in detai J, including, the mechanics and schedule. It will then focus on the technical progress made to date.

1?771 [3]Jet Propulsion Lab., [2]Aerospace Corp., [3]Daedalian Systems Corp., [4,17,1 8,22,23]Goddard Space Flight Center, [5]Microcosm, [6]Lockheed Missiles and Space Co., [8]Air Force Phillips Lab., [9]Hughes Space and Comm. Co., [10,15]Boeing, [11,19]Honeywell Satellite Systems, [12]Space Applications Corp., [14]Aero Astro, [16]Martin Marietta Astro Space, [20]Johnson Space Center, [21] Applied Physics Lab.

INTRODUCTION

in the life cycle of any industry, early efforts are characterized by bold yet disconnected developments led by one or a small group of organizations. As the industry evolves, certain types of elements and a basic approach become widespread, but the organizations involved tend to perpetuate the unique attributes of their products. This discourages cross fertilization, limiting innovation, and keeps costs relatively high, limiting markets. An effective stagnation point is often reached. The spacecraft industry is at such a juncture.

in the case of spacecraft activities, in particular, traditional funding sources have become intolerant of large budgets. This is true in all sectors of the spacecraft community.

in civil space, for example, the Pluto Express mission is being planned at $400M, the MESUR Pathfinder mission to Mars is planned at $ 150M, and the dominant trend within NASA is toward Discovery class missions at $150 and Small Explorer class missions at $35M. By way of comparison, budgets for flagship planetary missions once exceeded $1 B. This trend began in t e late sixties when the U.S. successfully landed men on the moon, was amplified greatly during the recessions of the seventy's and eighty's, and has become industry threatening with the end of the cold war. The U.S. public and congress now have little appetite or tolerance for large space expenditures (see, e.g., Ref. 1) as is evident from the multiple resets and continuous decline of support for the Space Station.

in commercial space, there is a major drive towards smaller satellites, faster development cycles and lower spacecraft costs. This is exemplified by the so called "Big LEO" space based telecommunication systems. In order to orbit large satellite networks, the system integration and test spans are being reduced below 2 months, with the total cost for each spacecraft being less than $25M. This is a significant reduction for systems that have generally cost between $1 OOM and $1 SOM, with a 9 month integration and test span. The cost pressure on space based telecommunication systems in particular is fueled in part by fierce competi tion from, for example, terrestrial fiber optical communication system developers.

The defense space community is by no means immune to cost pressures. For example, the Clementine mission was recently flown for a total cost of about $150M (including about $80M worth of inherited equipment) after 18 months of development. This contrasts with missions like Global Positioning System (GPS), Milstar and DSP which were developed in 5 to 6 years at costs between 0.5B to $2B. The future is typified by programs such as the Tactical Support Satellite (TSS) and Integrated Space Technology Flight (ISTF) which are intended to be developed over 3 year periods for costs between $250M to $500M for 4 to 5 satellite block buys.

The development of accepted standards, especially interface standards, has often proven to be the catalyst needed to overcome these kinds of developmental deadlocks and economic difficulties, encouraging the resumption of accelerated progress and opening up markets by allowing lower costs. This has been demonstrated in such industries as radio, television, high-fi, telecommunications, micro-computers and, most recently, fax (see, e.g., Ref. 2). Interface standards also make it convenient to decompose a system design problem into well defined elements, giving rise to new business opportunities, especially for small to mid size companies. Given the spacecraft industry's current difficulties, the benefits of standardization would appear to be essential.

The appropriate epoch for standardization within an industry is when that industry is mature, when the space of available design options and components is rich, and when the base of experiences is extensive. in this sense also, the spacecraft industry is at an ideal point for the formulation of effective standards.

To address this important need, The American Institute of Aeronautics and Astronautics (AIAA) has undertaken a new standards initiative in the area of spacecraft Guidance, Navigation. and Control (GN&C) subsystem interfaces. The central objective of this effort is to establish standards that will promote interchangeability of major GN&C components, thus enabling lower spacecraft development cost. The standardization targets are specifically limited to interfaces only, including information (i.e., data and signal), power, mechanical, thermal and environmental interfaces between various GN&C components and between GN&C subsystems and other subsystems. Adoption of particular hardware solutions, as was attempted in the NASA Standard Component

program of the seventies, is specifically not part of the objective. Moreover, a special effort is being made to formulate the standards in such a way that they do not constrain technology development.

The program scope encompasses spacecraft digital electronics buses and bus protocols, system architectures, computer, sensor and actuator interfaces, Software interfaces, cabling, Connectors, power requirements, thermal control interfaces, mechanical interfaces, form factors, materials, packaging, shielding, and spacecraft-ground system interfaces.

The success of the program will be measured by the extent to which, within the next three to five years, spacecraft GN&C subsystem designers can choose plug and play compatible hardware and software from a variety of vendors, expend little or no effort specifying the interfaces having confidence that all the interfaces will be compatible, and integrate and test the subsystem quickly and easily. At the same time, success will mean the introduction of new products, reflecting innovation, and offered at lower cost.

Support for the initiative is widespread, with active participation from industry (Hughes, Lockheed. Boeing, Martin Marietta, Honeywell, Microcosm, Acro Astro. Ithaco), NASA (GSFC, JPL, JSC) and the DoD (ARPA, APL, Aerospace Corp., Air Force). Responsibility for the coordination of the activity lies with AIAA's GN&C Committee on Standards (CoS).

The initiative is being carried out according the general procedures outlined in Ref. 3. These procedures are approved by the American National Standards Institute '(ANSI), and indeed it is expected that the documents produced through the program will receive ANSI endorsement. Endorsement by the International Standards Organization (1S0) will be pursued concurrently.

The committee's approach includes coordinating closely with related activities being carried out by the Institute of Electrical and Electronics Engineers (IEEE), the Society of Automotive Engineers (SAE), the Consultative Committee on Space Data Systems (CCSDS), the Strategic Avionics Technology Working Group (SATWG) and other groups concerned with space system standards. The committee focuses on the unique requirements of spacecraft GN&C components (e.g., star trackers and reaction wheels), exploiting the products of

other organizations where appropriate. The committee's current emphasis is on information interfaces between hardware elements.

SCHEDULE

A program schedule covering the first four years of what is expected to evolve into an ongoing effort is shown in Figure 1. The schedule reflects the goal of publication of one or more AIAA standards publications (i.e., Guide. Recommended Practice or Standard documents) on roughly two year centers. Standards will be reviewed, and if appropriate revised, within five years of publication in accordance with AIAA procedures (Ref. 3). The schedule includes a period of candidate standards testing at user facilities for each new document.
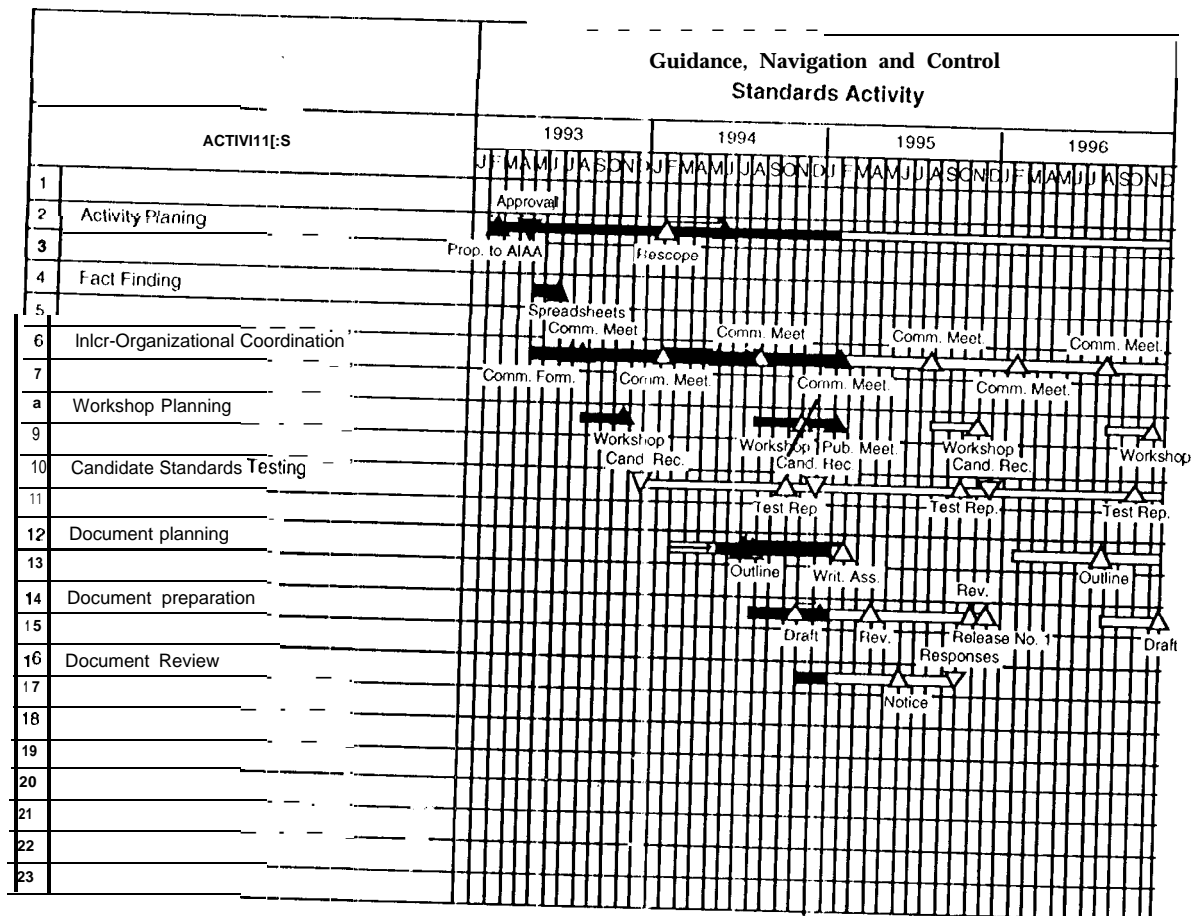

Figure 1. Program Schedule

5

FUNDING

The standards committee is comprised of volunteers from a broad cross section of directly and materially affected interest groups, including commercial GN&C system developers, NASA, DoD and GN&C component suppliers. The submission of standards for evaluation, as w c]] as the provision of test facilities and personnel, is also voluntary. AIAA provides clerical and administrative support, and support for publications, meetings and promotion.

PROGRESS TO DATE'

The committee has had five meetings (as of the date of the 1995 Keystone Conference) since the initiative was launched in August of 1993, one of which was a public meeting conducted as a workshop (see Figure 1). It was decided at the first meeting that the committee should limit its initial scope, as a pathfinder, to information interfaces between major hardware elements (Ref. 4). Scope expansions, to include more of the total interface problem (e.g., electrical and mechanical interfaces, etc.), will occur as experience is gained and as appropriate experts are added to the committee. These expansions will be taken up by dedicated subcommittees formed for the purpose. The following is a brief summary of the information interface standard in its current form.

The basic architecture of the avionics shall be open, allowing the possible combination of multiple interface types from a variety of suppliers in order to accommodate optimized solutions for particular applications (Ref. 5). The general framework is depicted in Figure 2.

The architecture allows a parallel back plane to support, for example, high speed direct transfers between processors and memory or peripheral devices. The parallel back plane will itself be one of a few (perhaps just one) recommended industry standards. Futurebus+, which is currently being defined by the IEEE and which will specifically include a space profile (Refs. 6-8), is being considered as t h e one recommended standard.

The architecture also allows a serial cable bus, a local area network (1. AN) and point-to-point interconnections, including point-to-point serial digital links and both analog and bi-level discrete links. The standard specifics that all GN&C peripheral devices (i.e., sensors and

actuators) communicate with the processor that bests the GN&C application software through the serial cable bus. Moreover, the standard specifics that all the information traffic to and from each peripheral device, including health and status data, be multiplexed and transferred over the serial cable bus. The SAE's fiber optic AS-1773 (Ref. 9), which is a dual rate (i.e., 1 and 20 Mbps) outgrowth of the Department of Defense's fiber optic MIL-STD- 1773 (Ref. 10), is being strongly favored for specification as the serial cable bus for (his standard. Note that although the architecture allows point-to-point interconnections, these are discouraged, and the standard provides no specific guidance on their implementation.

GN&C Host Computer System

Backplane
(one unique standard or
one of many accepted
standards)

Interface card (provided by host
computer vendor, peripheral device
manufacturer or third party)

Processor card

Point-to-point interconnection
over an accepted standard
interface, or analog channels, or
discretes

Spacecraft LAN (could be the
same as the serial cable bus
used for GN&C peripheral
devices)

GN&C
peripheral
device

Serial cable bus (AS-1773
currently being considered
for specific recommendation)

Peripheral
device
interface
(provided by
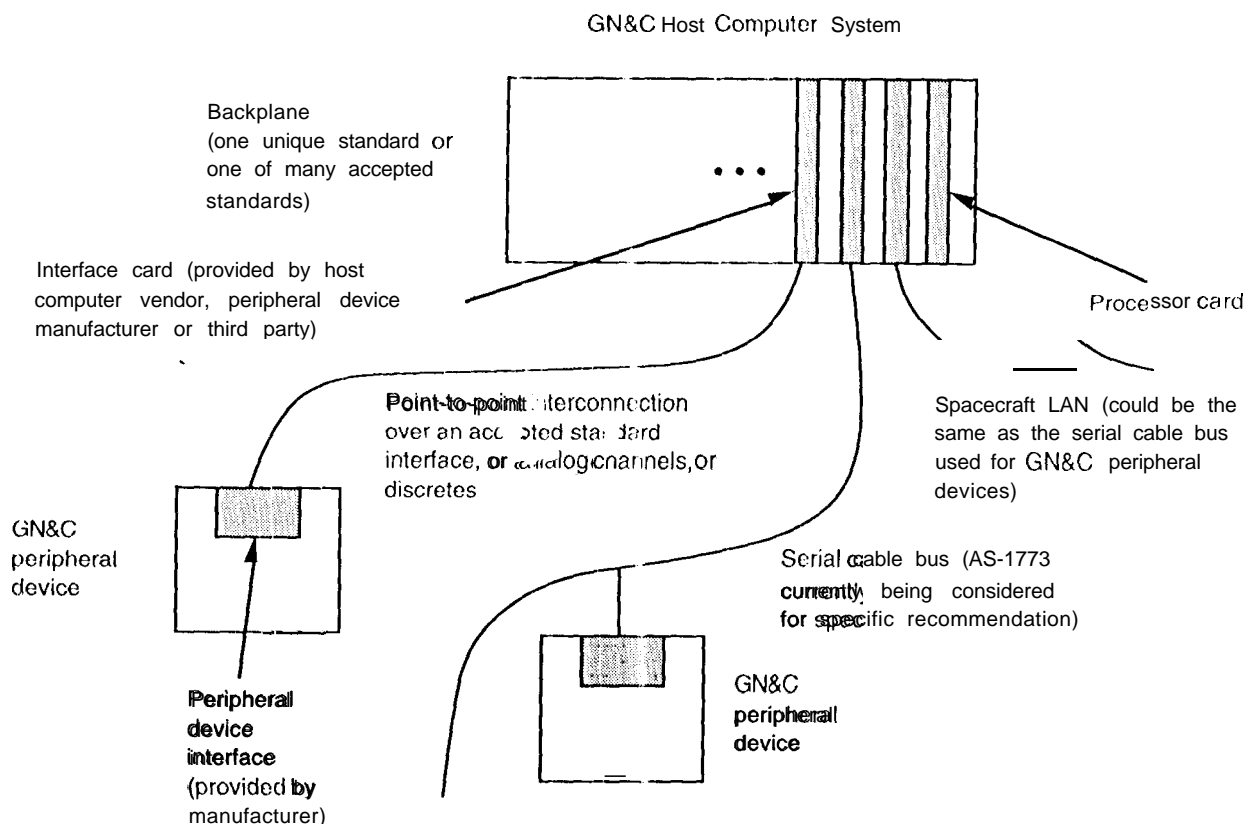manufacturer)

GN&C
peripheral
device

Figure 2. Architectural Framework

The LAN allows multiple subsystems on physically large spacecraft to conveniently exchange information. The question of which particular LAN or LAN's to specify for GN&C applications has not yet been considered.

Notice that the architecture automatically allows a GN&C subsys cm to be accessed through a wide area network (WAN) that may encompass multiple spacecraft and ground terminals (e.g., as in he Iridium or Teledesic systems [Refs. 11, 12]). That is, the GN&C subsystem could interface with a spacecraft telecommunication subsystem that includes a WAN terminal through either the I. AN, the serial cable bus, or a discrete link, though again the latter is discouraged.

A survey of typical GN&C peripheral devices revealed that some, like star trackers, arc generally sophisticated enough to accommodate a serial cable bus interface with minimal impact on [heir cost, mass, volume or power requirements. Indeed, some manufacturers of such components already offer them with MIL-STD-1553 interfaces, whose protocol is identical to that of AS-1773. On the other hand, others, like sun sensors, arc intrinsically of such simplicity that the introduction of a serial cable bus interface represents a substantial n c w addition. There.fore, full compliance with the standard is expected to take longer for some types of devices than others. However, considering the cost impact of the serial cable bus decision at the overall system level, the proposed standard is clearly beneficial, because the system level savings far outweigh the anticipated cost increase of peripherals.

For each specific type of GN&C peripheral device, the standard provides a definition of the information content, format, timing, and, where applicable, the order. It also provides a definition of the device level protocol (as opposed to the bus protocol), and the command, measurement, parameter and status dictionaries for each device type. A partial list of the devices covered to elate is shown in Table 1. For brevity, the definitions are not included in this paper. However, they will be pubicized at the conference, as they appear at that time, within a preliminary draft of the complete standard. Working definitions arc given in Refs. 13 and 14.

A generic representation of the flow of information in a GN&C system is shown in Figure 3. Under the proposed standard, the manufacturer of a GN&C sensor or actuator will be free to choose the level at which to define the information interface to their device based on the market they arc targeting and the expected profitability of that level for their particular product. This makes it possible for ncw types of devices, with either higher or lower level

data products or capabilities to be introduced at a later time within the genera] framework of the interface standard. However, the standard defines the interface at one particular recommended level reflecting the current state of the art and a reasonable projection of near term future developments. As per AIAA guidelines, the standard will reviewed and updated at least once every five years in order to keep pace with technology and market trends.

'System developers faced with the task of integrating noncompliant peripheral devices will be advised to accomplish this though an adapter that is itself compliant with the standard. Third party vendors will be encouraged to offer such adapters for popular non-compliant peripherals. Moreover, the AIAA GN& C CoS is prepared to commission the development of Recommended Practice documents (Ref. 3), to define low level interface recommendations (e.g., voltages, impedances, connectors, etc.) for such components.

<center>Table 1.   Hardware Elements Covered to Date</center>

> Star Sensors
> Sun Sensors
> Horizon Sensors
> Gyros
> Global Positioning, System Receivers
> Magnetometers
> Magnetic Torquers
> Thrusters
> Reaction/Momentun~ Wheels
> Control Moment Gyros
> Gimbals

RA'I'1ONALE FOR CHOICE OF AS-1773

The AS-1773 bus obviously plays a pivotal role in the proposed interface standard. It provides both the physical layer and elements of the data link layer of the peripheral device interconnections according to Open S ystem Interconnect (0S1) terminology (see, e.g., Ref. 1 5). As such, a few words about the rationale for its selection arc i n order.
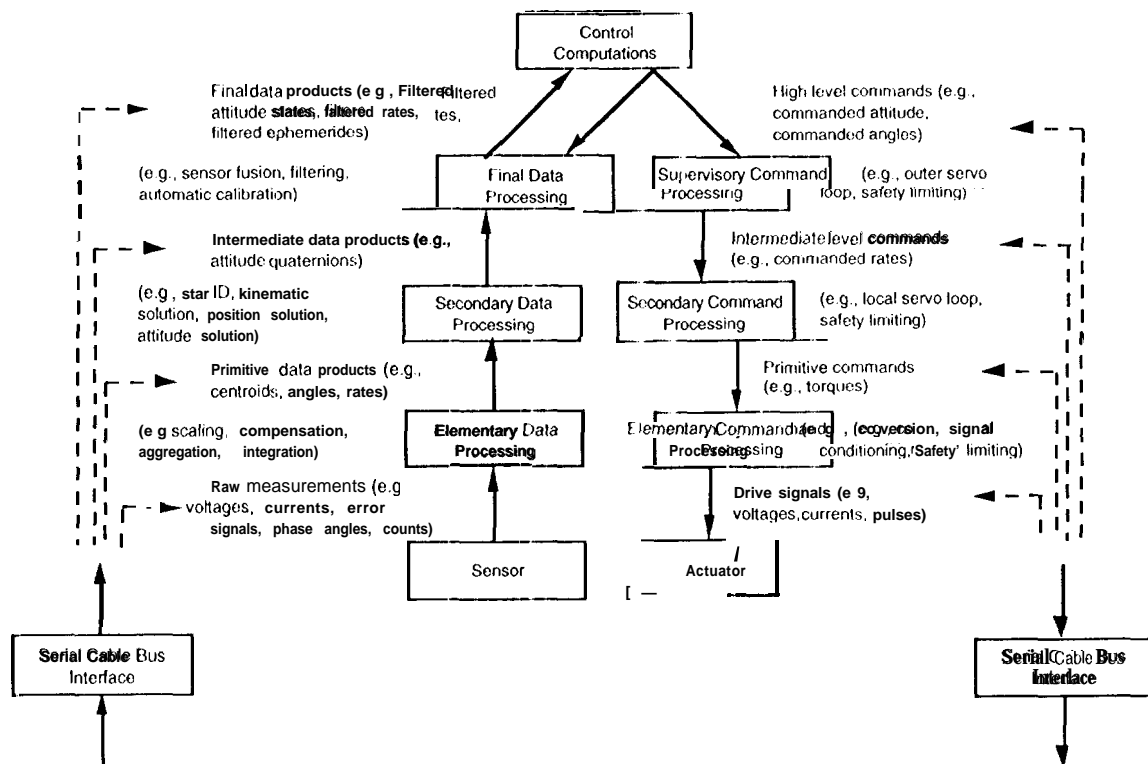
Figure 3.   Inter: acc Levels

AS-1773 is a multiplex data bus. It hus offers the benefits of both multiplexed point-to-point interconnections (namely, less cabling, and fewer physical interfaces to specify, design, build, integrate and test) and of a bus architecture (fewer sets of communication hardware, even compared with point-to-point links).   This is illustrated in Figure 4.

The AS-1773 bus in particular employs a fiber-optic physical channel.   This immediately makes a higher communication bandwidth possible (20 Mbps compared to, e.g., 1 Mbps for the electrical MIL-STD-1 55313), and provides a growth path to much higher bandwidths (see, e.g., Ref. 16).   It also virtually eliminates the problem of electromagnetic interference/electromagnetic compatibility (EMI/EMC).   in addition, AS-1773 has a relatively low mass and low power requirements (compared to MIL-STD-1 553), and offers intrinsic isolation between components.

Finally, the AS- 1773 bus is generally implemented with a star topology.   As shown in Figure 5, this topology is optimal with respect

1 0

to number of tap splices, and is nearly optimal with respect to number of in-situ connections required.

Incidentally, the 1 Mbps MIL-STD- 1773 data bus has already been flown by the Goddard Space Flight Center on its SAMPEX spacecraft, and hardware for the dual rate AS- 1773 has already been developed.
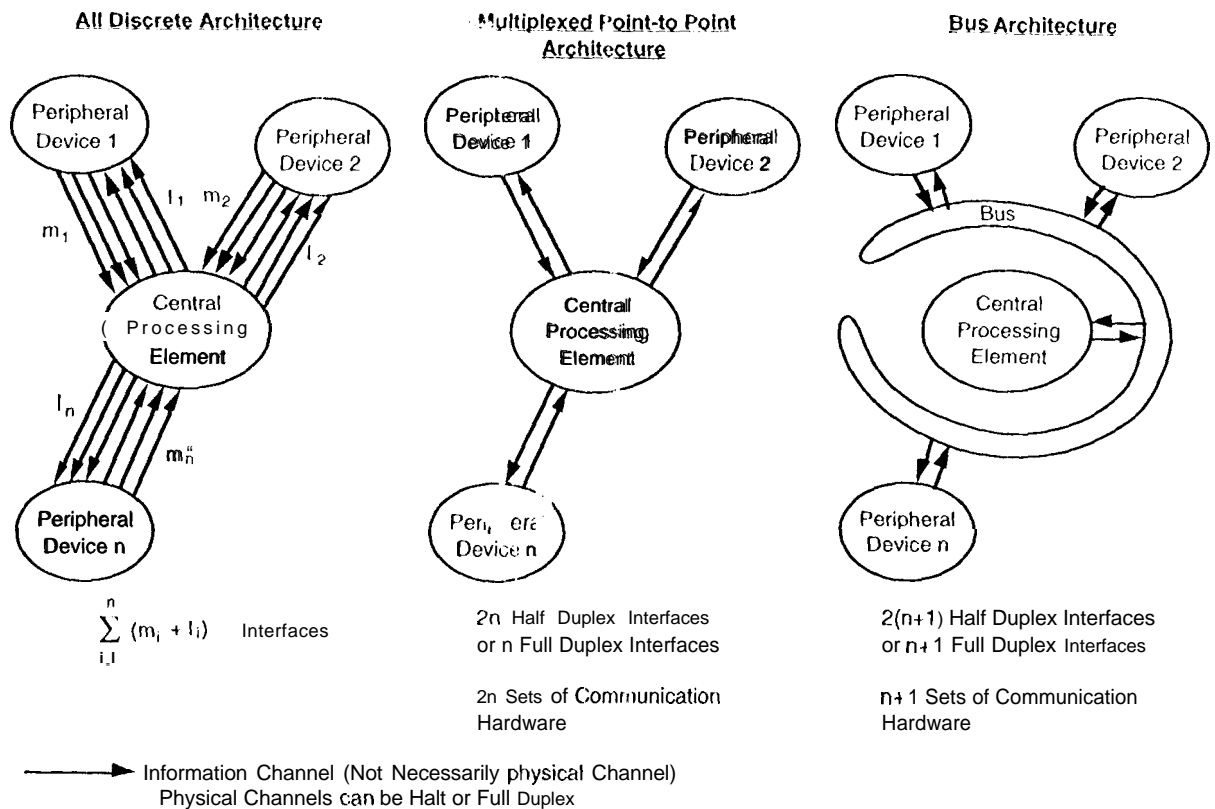
All Discrete Architecture   **Multiplexed Point-to Point Architecture**   **Bus Architecture**

$$\sum_{i=1}^{n} (m_i + l_i) \quad \text{Interfaces}$$

2n Half Duplex Interfaces
or n Full Duplex Interfaces

2n Sets of Communication
Hardware

2(n+1) Half Duplex Interfaces
or n+1 Full Duplex Interfaces

n+1 Sets of Communication
Hardware

⟶ Information Channel (Not Necessarily physical Channel)
Physical Channels can be Halt or Full Duplex

Figure 4. Basic Information Architectures

TIMING

Accurate timing and synchronization of critical GN&C functions will be ensured by broadcasting a timing announcement followed by a timing mark over the AS-1 773 bus. It is envisioned that the central processing element, which will be the nominal bus master, will have access to a sufficiently accurate reference clock for this purpose. Timing and synchronization accuracy's of better than 1 μ sec are expected to be achievable through this method.
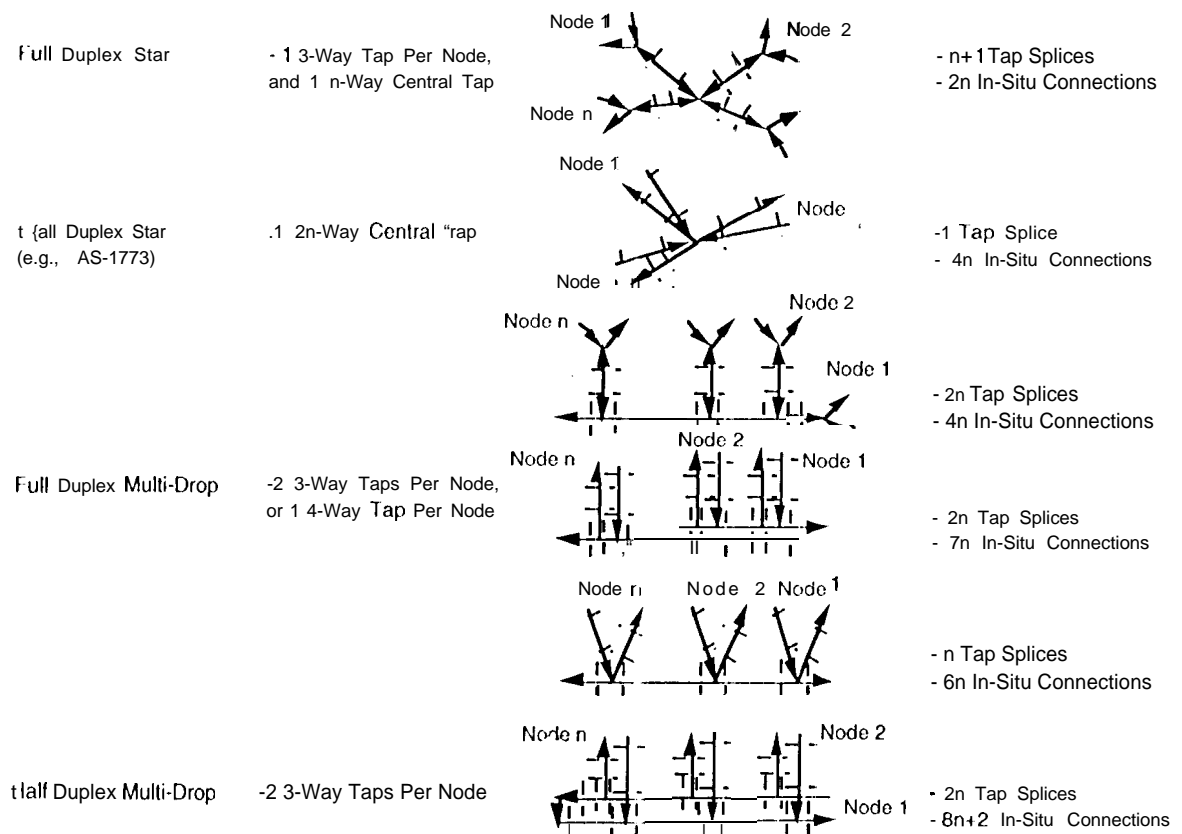
11

Figure 5.   Fiber-optic Bus Topologies

FUTURE WORK

Future work will focus, in part, on finalizing the definitions of the input and output information content, format, timing, and order for each of the GN&C peripheral devices identified as principal components, and on defining the device level protocol and the command, measurement, parameter and status dictionaries for each of those devices.   As reported above, this work has already started for many of the important GN&C peripherals. Indeed, in some cases, work has begun on devices not currently marketed commercially (e.g., magnetic torquer system).   Work on the important topic of cabling and connectors is just getting started.   As hewn in Figure 1, the committee plans to be ready for public balloting on the information interface standard by July 1, 1995, and plans to release that document by January 1, 1996.

SUMMARY

An overview of AIAA's GN&C interface standard initiative has been presented, and the current status of the effort has been described. Publication of the first recommended standard, which will cover information interfaces between major hardware elements is scheduled for January 1, 1996. As with all voluntary standards, his one will be the product of a broad cross section of materially interested parties, and will represent substantial agreement with n the community it serves. This paper is presented in a continuing effort to keep the public informed about the activities of the GN&C standards committee, and to invite active participation in the development of its products.

Expansions of the committee's scope only await the emergence of interested volunteers. The possibility of interface standards for GN&C software (e.g., between GN&C applications and each other, between GN&C applications and the host computer operating system, between GN&C applications and hardware drivers, and between hardware drivers and hardware) appears of be virgin yet particularly fertile ground. With the advent of automatic code generators, the time for such standards seems right. Other important areas awaiting volunteers to address them are the. mechanical, electrical, thermal and environmental interfaces of GN&C components, and the interface between the spacecraft GN&C system and ground resources. Interested individuals are urged to contact the authors.

ACKNOWLEDGMENTS

organizations for [heir persona] support and encouragement, and Mr. J. French of the AIAA for his valuable guidance. The authors would also like to express their gratitude to the American Astronautical Society (AAS), and in particular to the organizers of the AAS Guidance and Control Conference, for making the forum of the con ference avail able.

REFERENCES

1. C. Pellerin, "NASA Strategic Planning: A Status Report," Briefing to the Jet Propulsion Laboratory, June 7, 1993.

2. J. Cooperesmith, "Facsimile's false starts," IEEE Spectrum, February, 1993.

3. American Institute of Aeronautics and Astronautics Standards Program Procedures, AI AA, December, 1990.

4. "American Institute of Aeronautics and Astronautics Guidance, Navigation and Control Committee on Standards: Minutes of Meeting on Space Guidance, Navigation and Control System Interface Standards," Monterey, California, August 9, 1993.

5. AIAA Special Report: Guidance, Navigation And Control information Interface Standards, ISBN 1-56347-109-4, American Institute of Aeronautics and Astronautics, Walford, Maryland, 1994.

6. IEEE Standard for Futurebus+ - Logical Protocol Specification, IEEE Standard 896.1-1991, Piscataway, N. J., 1991.

7. IEEE Standard for Futurebus+ - Physical Layer and Profile Specification, IEEE Standard 896.2-1991, Piscataway, N. J., 1991.

8. IEEE Standard for Futurebus+ - Space Applications Profile, IEEE Standard P896. 10, draft publication pending.

9. Fiber Optics Mechanization of a Digital Time Division Command/Response Multiplex Data Bus - Draft 10, Society of Automotive Engineers, Warrendale, Pennsylvania, June 27, 1994.

10.   Military Standard: Fiber Optics Mechanization of an Aircraft Internal Time Division Command/Response Multiplex Data Bus, MIL-STD-1 773, Department of Defense, 20 May 1988.

11.   James R. Stuart, "New Approaches to Commercial Space Communication Systems, " AIAA Space Programs and Technologies Conference and Exhibit, Huntsville, Alabama, September 21-23, 1993.

12. Edward F. Tuck, "The First Mega LEO," Global Communications, Scptcn~bcr/October   1993.

13.   "Meeting Minutes: American Institute of Aeronautics and Astronautics Committee on Standards for Guidance, Navigation and Control Meeting June 8 & 9 As Part of First Annual AIAA Standards Meeting", Silver Spring, Maryland, June 8 and 9, 1994.

14.   "Meeting Minutes: American Institute of Aeronautics and Astronautics Committee on Standards for Guidance, Navigation and Control Meeting July 31, August 1, 2, 1994, " Scottsdale, Arizona, July 31 to August 2, 1994.

15. Space Generic Open Avionics Architecture (SGOAA) Reference Mode] Technical Guide, Johnson Space Center, December **1992.**

16.   Photobytes, Edition No. 4, November 1, 1994.